DEFECT DETECTION IN COPPER PRODUCTS WITH AN INFRARED LINE SCANNER

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INTRODUCTION

Copper products are used in a variety of industrial applications like heat sinks, electrical components, etc. The specific parts are originally manufactured from copper raw material, which the process will form into long tubes or wires having various kinds of different cross sections. The process usually generates several hundreds of meters of this wire, which is wound on a big drum. The drum is eventually sold to the manufacturer of the electric components, for example. However, defects can also occur in the manufacturing process. The defects usually take the form of delaminations, and because of the fast drawing speeds of the tube or wire, the delaminations can be several meters long. Another type of defect that forms in the product is a small air bubble. If heat is applied to the product, the bubble may burst open leaving a hole in the surface.

In this study, a preliminary inspection of selected copper products was performed in laboratory conditions. An infrared line scanning technique [1] was applied for defect detection in order to find out, whether the method would be suitable for use in industrial conditions.

NUMERICAL MODEL

The copper samples were 50 mm in length having rectangular cross sections with the width of 11 mm and the height of 6 mm (Fig. 1). The delaminations were expected to be found near the edges of the top surface at the depth of 0.5 mm, and the shapes of the delaminations were expected to take the form of long stripes, which are a couple of millimeters wide. The bubbles having a diameter of approximately one millimeter would form at the same areas.

In order to find out the surface temperature differences caused by the delaminations, the copper samples were simulated with a finite difference model having 20 x 240 x 15 grid points corresponding to the actual physical size of the samples. In the model, the top surface of a sample is heated with a moving line heat source having the width of 3 mm and the heating power of 100 W. A delamination simulated with a thermal contact resistance, $R_c = 10^{-4}$ m^2KW^{-1}, was placed under the surface of the sample at the depth of 0.5 mm.

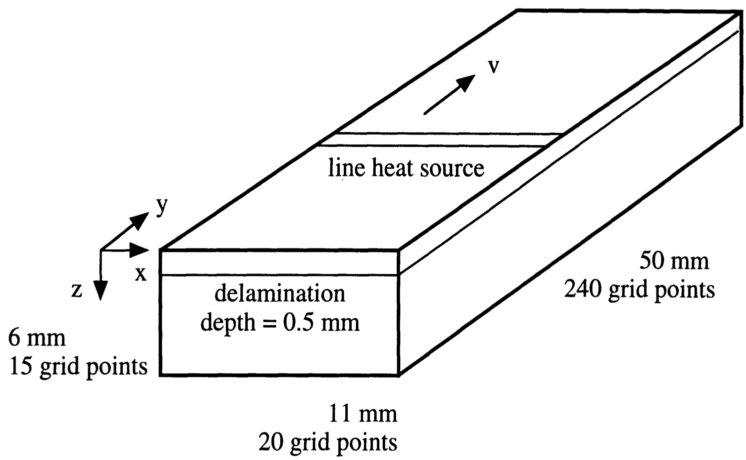

Fig. 1. A schematic drawing of the copper sample.

The objectives of the numerical simulations were to find out, whether the temperature difference caused by the delamination is high enough to be detected, and at what distance from the line heat source would the maximum temperature difference occur. For this purpose, it was sufficient to have a single delamination covering the whole area under the surface of the sample. The simulations were carried out at two heat source scanning velocities, $v = 2$ mm/s, corresponding to the velocity used in the laboratory, and $v = 2.5$ m/s, corresponding to the actual velocity used in the factory. The value used for thermal conductivity was 401 W m^{-1} K^{-1}, for specific heat 385 J kg^{-1} K^{-1}, and for density 8933 kg m^{-3}.

The results of the calculations are shown in Fig. 2 a) and b). Fig. 2 a) shows the surface temperature profiles in the case of $v = 2$ mm/s. The thinner lines represent the surface temperatures of a perfect and a delaminated sample. The thick line shows the temperature difference caused by the delamination, and it has been obtained by subtracting the two thinner curves from each other. Because the line heat source is very wide, the peaks of the profiles spread extensively. Furthermore, the thermal conductivity of copper is very high and the scanning velocity is very slow, for which reason a lot of heat escapes the heated area in the time scale of the simulation. As a result, the leading edge of the heating line is very shallow. From the thick curve, it can be seen that the maximum temperature difference, ΔT, is in excess of 30 K, and the delamination will be detectable. The maximum point occurs approximately 0.2 mm behind the heating line center. This point is the optimum position for detection. However, the selection of the detection point is not critical in this case, because the ΔT-values remain high several millimeters behind the line source center.

In the case of high scanning velocity (Fig. 2 b), the profiles look different. Because of the wide source, the peaks of the profiles are still wide. However, the leading edges of the thinner lines (surface temperatures) are now steeper. Furthermore, the higher scanning velocity results in lower peak temperatures and maximum temperature difference caused by the delamination. In this case, the maximum ΔT-value is only 0.2 K. Therefore, it is questionable, whether the delamination can be detected. The point of maximum temperature difference is now approximately 4.5 mm behind the line source center.

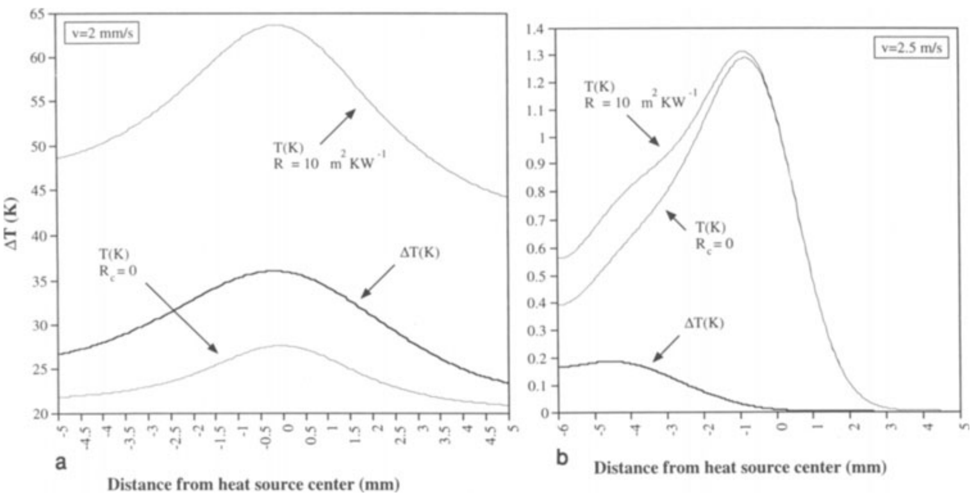

Fig. 2. The surface temperature profiles in the cases of a) v = 2 mm/s and b) v = 2.5 m/s. The thick lines are obtained by subtracting the lower temperature curves from the upper ones.

MEASUREMENT SYSTEM

The inspection of the copper samples were done using hot air jet heating and an infrared line scanning detection (Fig. 3). The sample under inspection was attached to a translation stage, and it was heated with the hot air jet directed through a line-shaped nozzle. The translation stage moved the sample against the air jet. By controlling the span and the velocity of the translation stage, the heated surface area could be chosen as necessary. Simultaneously with the heating, the infrared line scanner, consisting of an ac coupled MCT detector (detector area 25 µm x 25 µm), a Ge lens, and a deflection mirror, was used for monitoring the surface temperature alongside the heating line. The distance between the heating line and the detection was adjusted according to the numerical estimates. During one measurement, the line scanner performed 280 scans, each of which contained 180 pixels. The scans were recorded with a microcomputer, which composed the scans to a pseudo color image. The microcomputer was used to control the hardware of the measurement system as well. The measurement time for one thermal image was about 6 s.

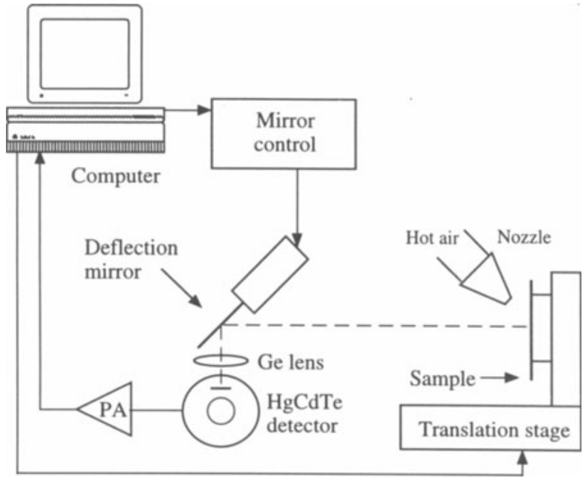

Fig.3. The measurement system.

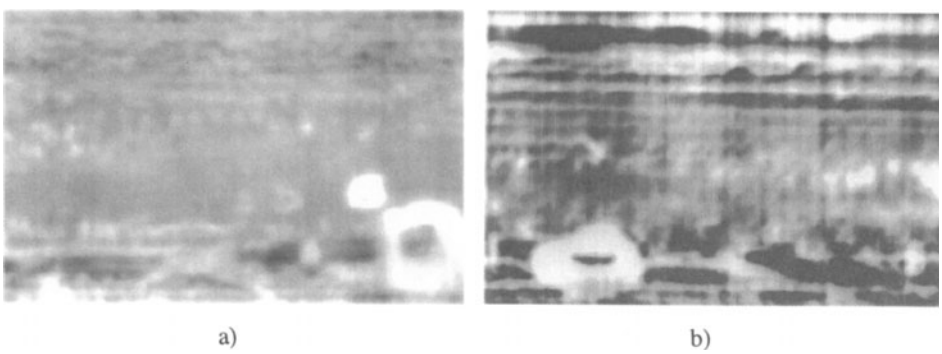

Fig. 4. a) A thermal image of two bubbles in a copper sample. The size of the imaged area is 16 mm x 9 mm. The size of the smaller bubble is 1 mm x 1 mm, and the larger one has dimensions 3 mm x 3 mm. b) A thermal image of a long, stripe-shaped delaminations in a copper sample. The size of the imaged area is 16 mm x 9 mm, and the width of an individual delaminated stripe is about 1 mm. The air bubble near the bottom edge of the image has dimensions 4 mm x 1.5 mm.

RESULTS

Figs. 4 a) and b) show two thermal images obtained from two different copper samples. The first image shows two bubbles in the lower right hand corner. Both the bubbles are clearly visible. The bigger bubble has the size of 3 mm x 3 mm and the smaller

1 mm x 1 mm. The size of the imaged area is 16 mm x 9 mm. The heating line was positioned in the vertical direction in the image, and it moved from left to right. There are stripe-shaped areas near top and bottom edges of the image that are in the expected positions. However, they are faint and do not show as significant temperature differences as the numerical simulations estimate. Also, the image suffers from distracting surface features. In the case of the second copper (Fig. 4 b), the stripes near the top edge of the image can be seen more clearly after image enhancement, although the image is still full of surface details. The width of an individual stripe is approximately 1 mm. The air bubble near bottom edge of the image is resolved clearly again. The size of the bubble is about 4 mm x 1.5 mm.

CONCLUSIONS

A preliminary study for finding delaminations in copper products was performed by using hot air jet heating and an infrared line scanner for detection. First results showed that the air bubbles formed in the manufacturing process were detected in the laboratory conditions. Stripe-shaped delaminations were observed in the areas where they were expected to be formed, although they appeared very faint. The surface emissivity variations posed a serious difficulty to the interpretation of the results. The temperature differences predicted by the numerical model were considerably higher than the actually observed ones.

REFERENCES

1. J. Hartikainen, Rev. Sci. Instrum. 60, 1334 (1989)